STEADY STATE PERFORMANCE OF ELITE CYCLISTS IN RECORD ATTEMPTS

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NOMENCLATURE

d_{Mean} is the error between the actual velocity and the mean velocity

e_{Mean} is the energy cost given by the error between the cube of the actual velocity and the cube of the mean velocity

s is the distance travelled by the front wheel contact area

t is the limiting time for work at maximal aerobic power

v_{Float} is the floating mean of velocities over current and preceding timed distances totalling 1km

v is the mean velocity over a 1km timed distance at the front wheel contact area

v_{Mean} is the mean velocity at the front wheel contact area over the full distance of the record

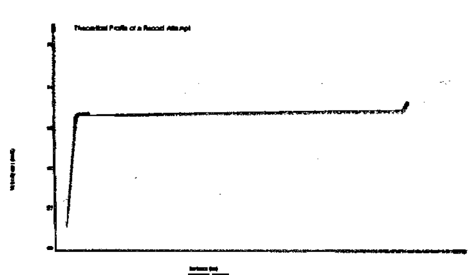
INTRODUCTION

This paper considers actual performances by top professionals and amateur riders in record attempts and examines performance from a recent world hour record attempt. It considers an energy based approach to model the performance of such an elite cyclist and compared this model with the ideal steady state.

Less than half of world records in the sport of cycling are permitted to be broken in international competition. As a result success tends to favour a dedicated attempt under ideal conditions rather than during the stress of competition, accordingly the majority of successful attempts have been made by professional road riders.

An example of the theoretical performance required to capture a world hour record is shown in 1 for a distance of 53.1 km, just beyond the existing record. Classical mechanics can be applied to the system of bicycle and rider if the power output of the cyclist is constant, which many previous studies upon endurance athletes have assumed. It is widely understood that for the maximal and supra-maximal effort involved in short distance events and sprinting the power output is neither constant or finite. The cyclists who make such attempts typically hold multiple World and Olympic championships. and can be considered as highly trained and experienced. Furthermore there is a relative advantage to the cyclists in that they can select the venue, time and ambient conditions of their attempt, consequently in comparison to athletes in other sports we should expect that their performances would lie close to the theoretical ideal shown in 1.

Figure (1) Theoretically required Steady State Performance



If the desired target of 53.1 km shown in 1 was to be achieved. some allowance must be made for the standing (stationary) start, perhaps a constant velocity of 53.2 kmh^{-1} would be required. At the finish the rider will inevitably raise their velocity which should present no problems to world class riders capable of sprinting at 70 kmh^{-1} after riding perhaps 200 km, four times the distance of the attempt. Overall we would therefore expect the attempt to be ridden at constant velocity apart from the first and last 1km to **2km** as shown in 1, hence the starting effort would demand energy from both **anaerobic** and aerobic energy mechanisms. The energy demand would develop into a steady state as the anaerobic energy stores are depleted and performance is limited by the capacity of the aerobic mechanism.

BACKGROUND

Expressions for the power requirements in athletics have been derived by a number of researchers; (Lloyd; 1966). (Lloyd; 1967). (Margaria; 1976). (Ward-Smith; 1984, **1985a, 1985b)** and (Perronet and Thibault; 1989). From a mathematical viewpoint, the relationships derived by these authors are in general agreement, with differences being due to varied approaches to defining and deriving the terms concerning the conversion of chemical energy. The work of Lloyd (1966) on world records in athletics was extended by Perronet and Thibault (1989) who defined the distinction between a long duration (endurance) event and a short duration (sprint) event by the **maximum** period for which the athlete could sustain maximal power, which they termed the limiting time, t. Unfortunately little comparable work has been carried out for cycling based exercise, although a typical value for t of 300 seconds would loosely agree with the transition between the **1000m** and **4000m** distances shown in 1. We couold therefore assume that cycling records over **4000m** distance are endurance efforts requiring a constant velocity as discussed above.

The forces acting upon the cyclist are largely similar to those acting upon an athlete, the principal component being the term, $\frac{1}{2} r C_d A v^2$, which models the forces due to the aerodynamic drag upon the **bicycle/rider** system. This is a standard expression in aerodynamics and is valid for the range of velocities encountered. The integration **of** this term with respect to **time** produces a v^3 term which **becomes** highly significant compared to **the** order and magnitude of the other terms involved, representing about 90% of the nett energy expenditure compared to **perhaps** 70% for running.

Table (I) - Mens World Records

Velodrome	Distance (m)	Time (s)	Mean Vel. ($m\ s^{-1}$)
Moscow	200 FS	10.099	19.80
Moscow	500 FS	26.649	18.76
Moscow	1000FS	57.260	17.46
Col. Spr.	1000	62.091	16.10
Moscow	4000	268.900	14.88
Leicester	5000	338.083	14.79
Bordeaux	10000	690.844	14.48
Bordeaux	20000	1376.485	14.53
Bordeaux	52270	3600.000	14.52

Burke & Kyle (1984) discussed all the mechanical and aerodynamical factors affecting cycling performance, observing that power losses through aerodynamic drag were far more critical than those lost through frictional drag. Their predictions were made using constant power models similar to 1. Their data was principally derived from field based experimental work and the authors recognised the problems and limitations with their results.

Ward-Smith **(1984,1985a,1985b)** carried out an analysis of running based upon overall energy of the athlete and considered the time dependency of aerobic and anaerobic energy production for elite athletes over **100m** to **10,000m,** together with the effect of wind and altitude. The energy expressions he derived were based upon an exponential rate for the depletion of the anaerobic energy reserve and a constant rate for the utilisation of **aerobic** energy.

Kyle (1988) carried out an analysis of the frictional forces acting upon the cyclist to predict performance variations with bicyclelrider mass, wind and hills. The expression used in his model does not appear to consider the variation in the available power which Ward-Smith (1984,1985) considered. although it introduces a value for the wind velocity, v_w. The force considered in this analysis considers the phasic and cyclical nature of the pedalling action which generates it, but does not extend it to consider the cyclist generating this power.

METHODOLOGY

Previous work carried out upon athletes has been based upon determining constants to characterise the maximum sustainable metabolic rate, frequently applying linear regression to performances such as world records (Ward-Smith 1984. 1985). The current mens flying and standing start world records are shown in 1. The period of acceleration lasts at least 5 seconds of acceleration to the optimum velocity and to some extent this is supported by the variation between the 1000m flying and standing start times shown in 1.

For a number of world hour record attempts the velocities achieved over each kilometre have been determined. 2 shows plots of 5 such attempts.

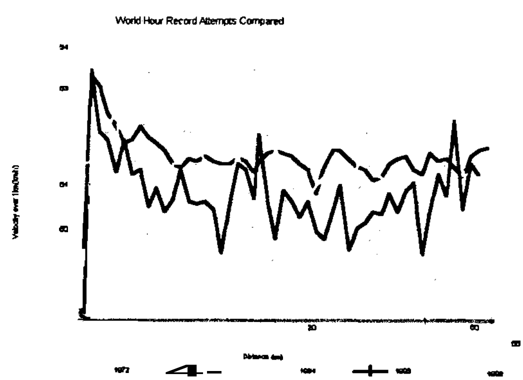
Field data from cyclists is generally restricted to distanceltime coordinates and although bicycle mounted electronic speedometers have been available for some time their resolution is relatively poor at around 0.1 kmh^{-1}. Calibrated electronic timing is used in international competition, reading to 0.001 second which reflects a resolution in terms of velocity of 0.8×10^{-4} kmh^{-1}. Calibrated manual chronographs are used as backup to the electronic systems, these 'are read to 0.1 second given that human reaction time is of this order. The cyclist is therefore unlikely to be aware of his actual performance during the attempt and must rely on analysis and instruction from coaches at the trackside.

The deviation in velocity from the theoretical ideal has been analysed for a number of successful hour record attempts and the associated energy cost for each kilometre travelled modelled by considering the differences between the cubes of the velocity over the 1km distance against the mean velocity for the attempt.

RESULTS

Two initial observations may be made of the 5 record attempts shown in 2, firstly that the velocity in the first 2 to 3 kilometres is significantly higher than that attained in the remainder of the attempt and secondly that variations in velocity are evident throughout the attempts. Cursory examination of the top plot shows that it generally exhibits minimal variations in velocity compared to the others. Unlike athletics tracks, cycle tracks are not always of a standard lap distance and more detailed analyses on a lap by lap basis are not always possible.

Figure (2) - Recent Successful World Hour Record Attempts



The velocity "error" for each 1 km interval can be determined from the relationships :-

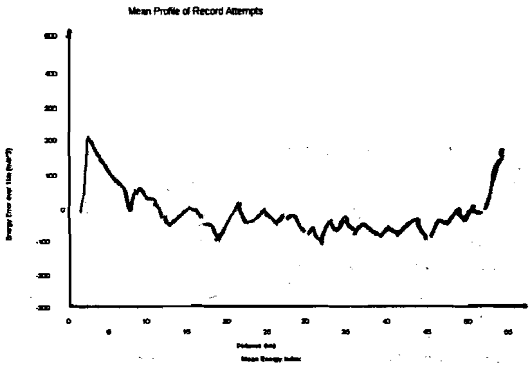
$$d_{Mean} = v - v_{Mean}$$

These results are shown in 5. This shows that riders generally maintain a significantly higher velocity than is actually required over the first 15 km of the attempt. Performance then gradually **falls** until the final few kilometres and a final effort is made over the last 3 km of the attempt when velocities approach those at the start.

The energy "cost" for each 1 km interval can be simply modelled from the **aerodynamic term** defined above by the relationship:-

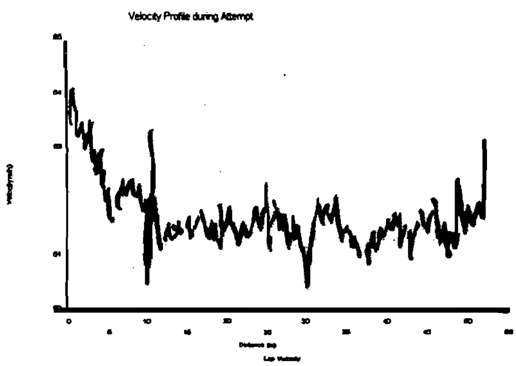
$$e_{Mean} = v^3 - v_{Mean}^3$$

Figure (3) - Analysis of Record Performances



These results **are shown** in 3. This shows that the energy expended in the early **part** is significantly greater than the variations evident during the latter part of the attempt. Energy variations during the main part of the attempt indicate that the rider is either physiologically incapable of maintaining a higher level of performance for more than 3 or 4 **kilometres** or that the **rider** is inadequately sensitive to changes in velocity until coaches have recognised the fall in speed and returned this information. Obviously as the rider can stop once the attempt is over supra-maximal levels of energy expenditure can be incurred over the closing stages of the attempt providing that this is judged **correctly.**

Figure (4) - World Hour Record Performance

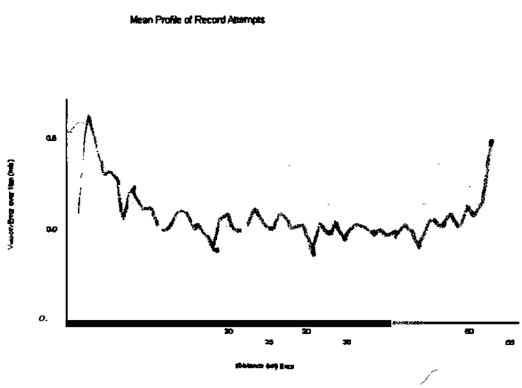


A more detailed velocity profile for one of the recent hour attempts can be seen in **4.** In this attempt a target velocity of **52.0 kmh^{-1}** was set and as-with most previous attempts, intermediate records were also attacked. The maximal velocity of **54.05** kmh^{-1} was attained shortly after the start and the minimal velocity of **50.30 kmh^{-1}** just-beyond the **10km** point.

The increased detail visible in **4** shows that the velocity is constantly varying. Even when a localised trend is clearly identifiable, the velocity and thus energy expenditure deviate from the trend.

Conconi and **Ennis (1991)** observed similar **behaviour** in preceding successful and unsuccessful attempts, three of **those discussed are shown in** 2. They felt that the cyclists had started too fast in many of the attempts and in some cases it was evident from the subsequently diminishing performance that the attempt would fail. In some cases this could be caused by attempts on the intermediate distances, however in instances where the intermediate records were not attacked the velocity profiles are similar to those in which they are attacked.

Figure (5) - Analysis of Record Performances

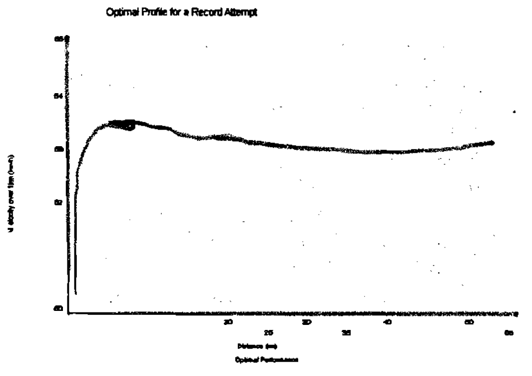


The resulting velocity profiles could therefore be presumed to be a function of the way a rider expends their energy rather than a function of an energy-minimising path.

The velocity after the start has typically been in excess of **54 kmh^{-1}** and this peak velocity is rarely regained. The maintenance of the positive energy in the early part of the attempt indicates that the riders are capable of maintaining a higher level of energy expenditure over such distances, but their failure to maintain this level for the first half of the attempt undoubtably places them under intense pressure. For the attempt considered here the target velocity was not approached over any floating **1km** interval. although at times the cyclist was travelling well in excess of the target, velocity required as can be seen in Macro-cycles are evident of fatigue and recovery.

Figure 6 shows a curve we would hypothesise would set a new record based upon **optimising** the energy expenditure of previous attempts. We would expect improvements upon existing or future records to be attained by closer conformity to optimal profiles such as that shown in 6. There is little evidence that the theoretically optimal profile of 1 is either being scheduled or ultimately attained by elite cyclists undertaking such attempts.

Figure (6) - **Hypothesised** Curve for a new Record of 53.1 km



In most of the **10km**, **20km** and hour record attempts examined, we would agree with Conconi and **Ennis** (1991) that the riders do appear to have started too fast. Riders who have made numerous attempts appear to develop better control, two of the attempts analysed here were made by such a rider. However riders who have related track experience in the individual pursuit (three of the attempts) or time trial events (four of the attempts) do not appear to have **innate** advantage over the rider whose experience was more limited in these respects.

Factors such as nervousness, adrenaline and motivation may influence the level of performance at various stages, but are generally identifiable. The model can be extended to other spheres of interest, such as other sports and certain cardiac patients with **arrythmia's,** given suitable adjustments to the terms for aerodynamic drag and tyre friction.

There is some evidence from performances in the world hour record attempts that the rates of decline, u and f do alter the performance curves once the limiting time of around 300 seconds has been passed.

Hopefully, this model could be extended by other researchers to encompass factors which were not accounted for in this paper.

Intermediate velocities show a variation of typically 5% about the mean velocity ultimately achieved. The degree of **psychological** and neuromuscular control exercised by such cyclists appears to indicate that better performances may be produced by improvements in "control skills" than "strength and endurance" for cyclists at such elite levels.

If energy efficiency is considered it is obvious that muscular energy is still wasted by variations in the velocity, even with elite level competitors and there seems to be a case for modifying the velocity profile in such attempts by additional training in technique.

CONCLUSIONS

a) Assessment of performance in the training programs of elite cyclists utilising either lap times or time over a given distance only, without considering the energy variation involved provides information of little value

b) Elite cyclists appear unable to maintain a steady state of energy expenditure in world record attempts, though the reasons for this are unclear

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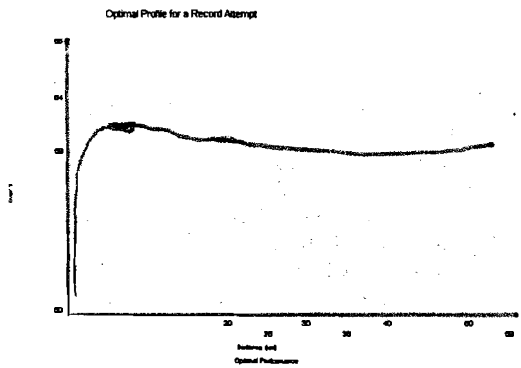

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c) Elite cyclists appear to have over performed in the first 20 minutes of a one hour record attempt, whether or not intermediate records are attempted.

d)For the performance examined here, a considerable amount of over expenditure of energy is evident, particularly when the energy requirements to maintain the mean velocity actually attained are considered.

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